Geological Survey of Canada
Commission géologique du Canada

GEOLOGICAL SURVEY OF CANADA
PAPER 85-16

GEOPHYSICAL MAPS AND GEOLOGICAL SECTIONS OF THE LABRADOR SEA

compiled by
S.P. SRIVASTAVA

Prepared in co-operation with
Canadian Hydrographic Service
Department of Fisheries and Oceans

1986

Canada

86-04939/

GEOLOGICAL SURVEY OF CANADA
PAPER 85-16

GEOPHYSICAL MAPS AND GEOLOGICAL SECTIONS OF THE LABRADOR SEA

compiled by
S.P. SRIVASTAVA

The bathmetry, gravity and magnetic anomaly maps accompanying this report were prepared and published by the Canadian Hydrographic Service, Department of Fisheries and Oceans and permission to include them is gratefully acknowledged.

1986

© Minister of Supply and Services Canada 1986

Available in Canada through

authorized bookstore agents and other bookstores

or by mail from

Canadian Government Publishing Centre
Supply and Services Canada
Ottawa, Canada K1A 0S9

and from

Geological Survey of Canada offices:

601 Booth Street
Ottawa, Canada K1A 0E8

3303-33rd Street N.W.,
Calgary, Alberta T2L 2A7

100 West Pender Street
Vancouver, British Columbia V6B 1R8
(mainly B.C. and Yukon)

A deposit copy of this publication is also available
for reference in public libraries across Canada

Cat. No. M44-85/16E Canada: $40.00
ISBN 0-660-12043-7 Other countries: $48.00

Price subject to change without notice

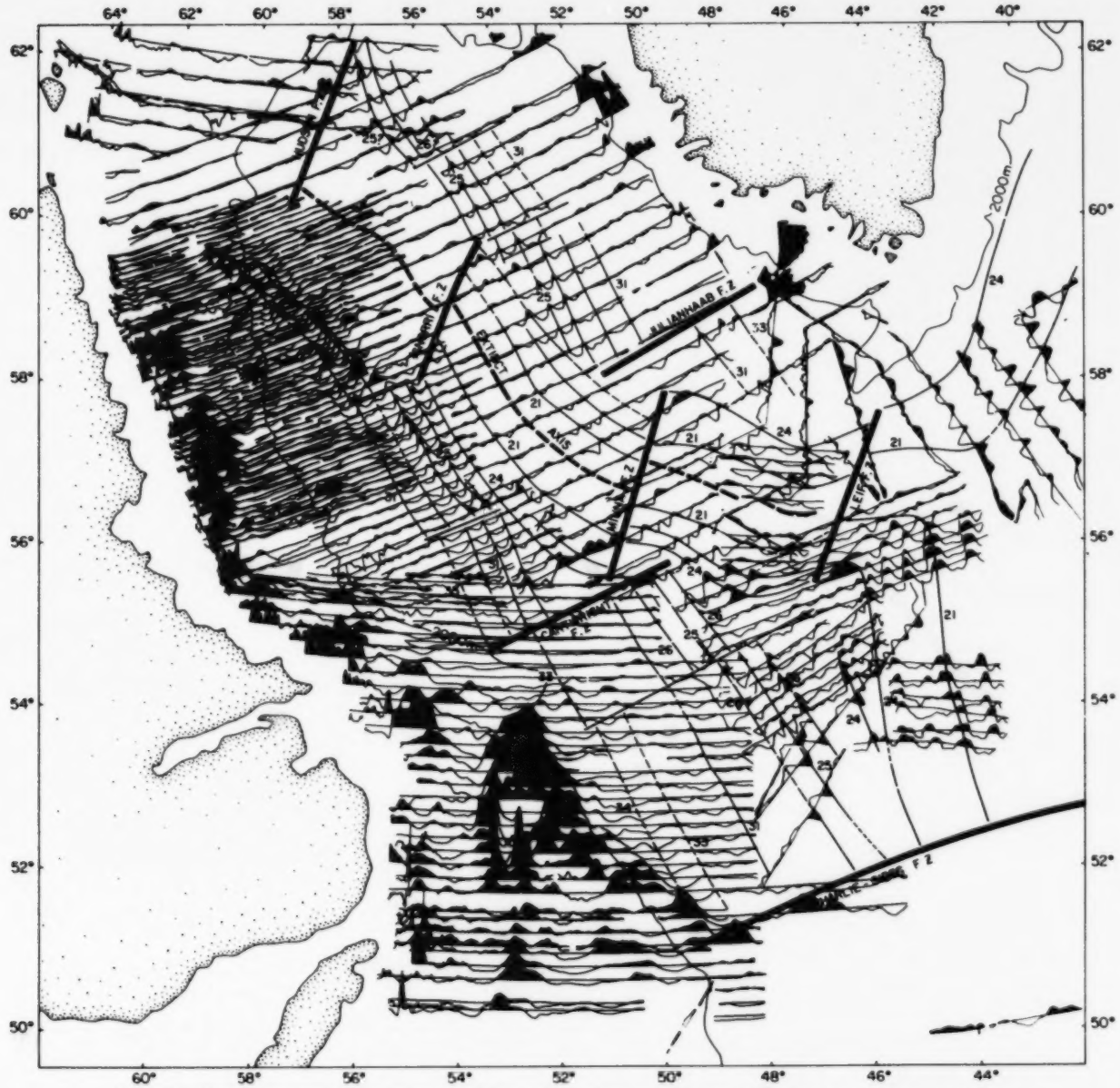
Authors' Addresses

Atlantic Geoscience Centre
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
B2Y 4A2

Final manuscript approved for publication: 1985-07

CONTENTS

1	Abstract/Résumé
1	Introduction
3	Lithostratigraphy
3	Introduction
3	Lithology
6	References
7	Stratigraphy of the Labrador Shelf and northern Grand Banks
7	Introduction
7	Mesozoic-Cenozoic stratigraphy
7	Interpretion of depositional environments
7	Radiometric age determinations
8	References
9	Depth to basement and sediment thickness
9	Depth to basement
9	Sediment thickness
9	Acknowledgments
9	References
10	Canadian Hydrographic Service maps
10	Gravity, magnetic anomaly, and bathymetry
10	Acknowledgments
10	References
	Table
4	1. Data on offshore wells
	Figures
2	1. Locations of wells drilled on the Labrador Shelf and northern Grand Banks
in pocket	2. Lithostratigraphic sections of the Labrador Sea
3	3. Lithostratigraphic classifications of Labrador Shelf sediments
in pocket	4. Sediment ages based on foraminifers and palynomorphs in wells facing the southwestern Labrador Sea
in pocket	5. Cretaceous and Tertiary depositional history of wells in Figure 4
in pocket	6. Depth to acoustic basement in the Labrador Sea
in pocket	7. Sediment thickness in the Labrador Sea
	Canadian Hydrographic Service Maps
in pocket	Map 814A Bathymetry, Labrador Sea
in pocket	Map 814B Gravity (free air anomaly), Labrador Sea
in pocket	Map 814D Gravity (Bouguer anomaly), Labrador Sea
in pocket	Map 814E Magnetic anomaly, Labrador Sea



Magnetic lineations, fracture zones and the extinct ridge axis in the Labrador Sea as obtained from the correlation and identification of magnetic anomalies. (After S.R. Srivastava and Tapscott, 1985).

Srivastava, S.R. and Tapscott, C.R.
1985: Plate Kinematics of the North Atlantic, in The Geology of North America: The Western Atlantic Region. eds. B.E. Tucholke and P.R. Vogt. GSA Special Publication.

GEOPHYSICAL MAPS AND GEOLOGICAL SECTIONS OF THE LABRADOR SEA

Abstract

The lithology, stratigraphy, and depositional environments of Mesozoic-Cenozoic strata on the Labrador Shelf are described using offshore well data. Bathymetry, gravity, magnetic anomaly, depth to basement, and sediment thickness of the Labrador Sea are presented at a scale of 1:2 000 000.

Résumé

Ce rapport renseigne sur la lithologie, la stratigraphie et les milieux sédimentaires des strates mésozoïques-cénozoïques de la plate-forme labradorienne à partir de puits de forage en mer. La bathymétrie, la gravité, les anomalies magnétiques, la profondeur du socle et l'épaisseur des sédiments de la mer du Labrador sont illustrées à l'échelle du 1/2 000 000.

INTRODUCTION

S.P. Srivastava

In the 1960s scientists worldwide were carrying out geological and geophysical surveys of the ocean bottom to answer the problems of seafloor spreading and continental drift and to define new areas with an energy or mineral resource potential. The Labrador Sea is one of these areas.

The Labrador Sea is a relatively small basin bounded by Labrador and southern Baffin Island on the west and by Greenland on the east. As little was known about its seafloor and subsurface many scientific surveys were conducted by research institutions and government agencies. In the mid-sixties, detailed bathymnetric and geophysical surveys in the Labrador Sea were carried out by Canadian and Danish government agencies to increase their knowledge of the structure and sediments of the sea floor and to provide accurate navigational charts.

Thus over the past two decades, a large amount of geological and geophysical data has been collected on the shelves, slope, and deep basin of the labrador Sea. The exploratory drilling by companies looking for hydrocarbons has also increased our knowledge of the geometry, stratigraphy and sedimentology of the subsurface of the shelf. Most of this information can be found in the literature either in scientific journals or in various government reports.

The geophysical and geological maps and figures of the Labrador Sea contained herein provide the user with a single source for much of this information. They were compiled, for the most part, from data collected jointly by Canadian Hydrographic Services and Atlantic Geoscience Centre operating from the Bedford Institute of Oceanography in Dartmouth, Nova Scotia. However, other government agencies, research institutions and exploration companies have also provided data used in the compilation of maps and figures in this volume. Sources of the data used are acknowledged individually in the description of each map or figure. As differences exist in accuracy and diversity of the data, certain smoothing procedures were followed to merge the data. These procedures are described in the appropriate sections.

The Canadian Hydrographic Service of the Department of Fisheries and Oceans has contributed four maps from their National Resource Series to this volume: Bathymetry (CHS Map 814A), Gravity: Free air anomaly (CHS Map 814B), Gravity: Bouguer anomaly (CHS Map 814D), and Magnetic anomaly (CHS Map 814E).

Dans les années 1960, partout dans le monde, des scientifiques exécutaient des levés géologiques et géophysiques du fond océanique, afin de faire la lumière sur l'expansion du fond marin et sur la dérive continentale et de définir de nouvelles régions qui pourraient renfermer des ressources en énergie ou en minéraux. La mer du Labrador est l'une de ces régions.

La mer du Labrador couvre un bassin relativement petit qui est délimité, à l'ouest, par le Labrador et la pointe sud de l'île Baffin, et à l'est, par le Groenland. Étant donné que l'on connaissait peu son lit et les formations sous-jacentes, des instituts de recherche et des organismes gouvernementaux ont exécuté un grand nombre de levés scientifiques. Au milieu des années 1960, des organismes canadiens et danois ont procédé à des levés bathymétriques et géophysiques détaillés dans la mer du Labrador afin d'augmenter leur connaissance de la structure et des sédiments du fond marin et d'établir des cartes de navigation fiables.

Ainsi, au cours des vingt dernières années, une grande quantité de données géologiques et géophysiques a été recueillie relativement aux plates-formes, à la pente et au bassin profond de la mer du Labrador. Les forages d'exploration menés par des sociétés à la recherche d'hydrocarbures ont également augmenté notre connaissance de la géométrie, de la stratigraphie et de la sédimentologie des formations souterraines du plateau continental. La plus grande partie de cette information a été publiée, soit dans des périodiques scientifiques, soit dans différents rapports gouvernementaux.

Le présent document renferme des cartes et des figures géologiques et géophysiques de la mer du Labrador qui rassemblent la plus grande partie de cette information. La plupart des cartes et des figures ont été établies à partir des données recueillies par une équipe du Service hydrographique du Canada (SHC) et du Centre géoscientifique de l'Atlantique qui est installée à l'Institut océanographique de Bedford, à Dartmouth (Nouvelle-Écosse). Toutefois, d'autres organismes gouvernementaux, des sociétés d'exploration et des établissements de recherche ont également fourni des données qui ont été utiles dans la compilation des cartes et des figures apparaissant dans la présente publication. Les sources des données sont mentionnées séparément dans la description de chaque carte ou figure. Étant donné la diversité et les différents degrés de précision des données, certaines méthodes de lissage ont été suivies afin de fusionner les données. Ces méthodes sont décrites dans les sections pertinentes.

The lithological and biostratigraphical data were generated by Geological Survey of Canada scientists from studies of logs, well history reports, and cuttings of samples from deep exploratory wells drilled on the Labrador Shelf (Fig. 1). Other parameters described in this compilation are depth to basement and sediment thickness containing brief descriptions of the method used in compiling each parameter, the source of the data, and the authors.

Acknowledgments

This publication is a result of work by many people from the Atlantic Geoscience Centre of the Geological Survey of Canada, the Gravity and Geodynamics Division of the Earth Physics Branch, and the Canadian Hydrographic Service. I wish to thank them all.

Le Service hydrographique du ministère des Pêches et Océans a autorisé la publication dans le présent document de quatre cartes de la série concernant les ressources du Canada: Bathymétrie (carte n° 814A du SHC), Gravité: anomalie à l'air libre (carte n° 814B du SHC), Gravité: anomalie de Bouguer (carte n° 814D du SHC) et Anomalie magnétique (carte n° 814E du SHC).

Les données lithologiques et biostratigraphiques ont été recueillies par les scientifiques de la Commission géologique du Canada, par le biais de l'examen des diagraphies, des rapports de forage et des coupes d'échantillons provenant de puits d'exploration profonds percés dans le plateau continental du Labrador (fig. 1). Parmi les autres paramètres décrits dans la présente, notons la profondeur d'eau et l'épaisseur des sédiments, lesquels sont accompagnés d'une brève description des méthodes utilisées pour déterminer chaque paramètre, de la source des données et des noms des auteurs.

Remerciements

La présente publication a été rendue possible grâce au travail d'un bon nombre d'employés du Centre géoscientifique de l'Atlantique, Commission géologique du Canada, de la Division de la gravité et de la géodynamique, Direction de la physique du globe, et du Service hydrographique du Canada. Je tiens à mentionner combien j'apprécie leur collaboration.

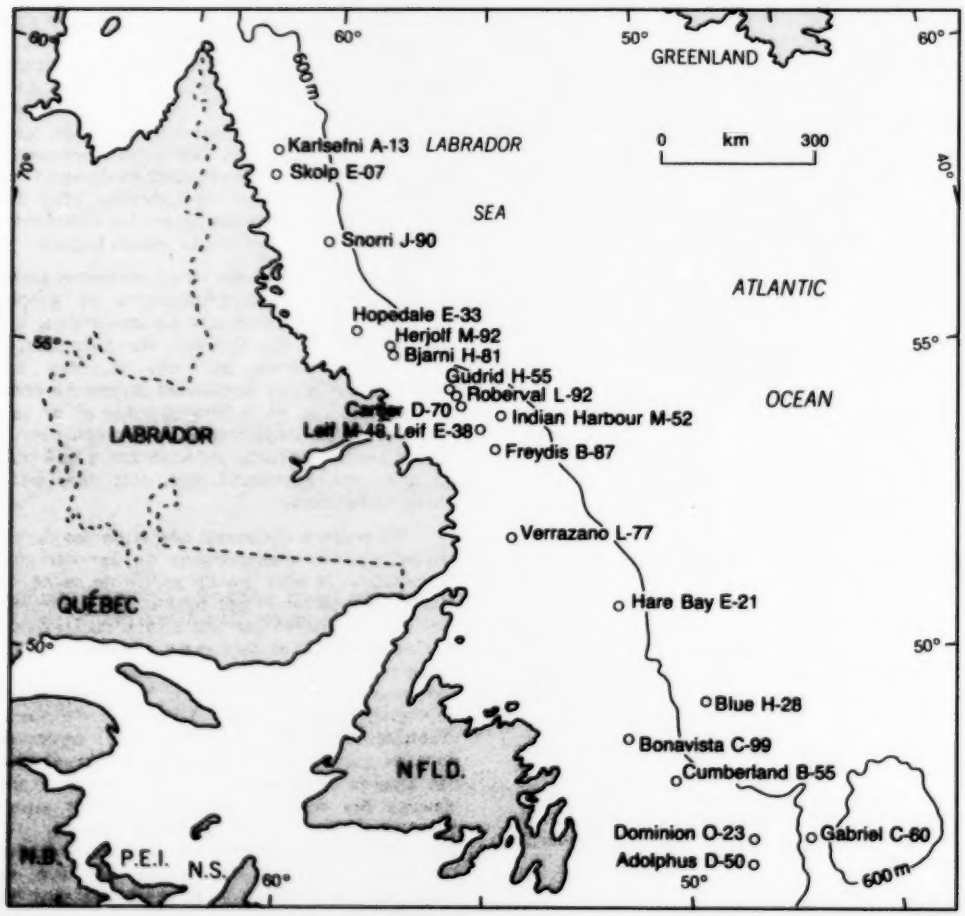


Figure 1. *Areas in the Labrador Sea are covered by multiparameter survey data in GSC open files.*

LITHOSTRATIGRAPHY

F.M. Gradstein

Introduction

Lithostratigraphic sections of the Labrador Shelf (Fig. 2) were compiled by D.C. Umpleby and modified by F.M. Gradstein. Figure 2 presents the lithology, sonic log (right), and gamma ray log (left) for 13 exploratory wells drilled on the shelf (Fig. 1). Data were derived from drill samples and well history reports (curated by the Department of Energy, Mines and Resources, Dartmouth), and from previous reports by Umpleby (1979), McWhae et al. (1980), and Gradstein and Williams (1982).

Figure 3 summarizes the predominant lithology, stratigraphic classification, and depositional interpretation of the Labrador margin wedge. Differences in nomenclature and interpretation are shown which highlight further areas of research, particularly the biostratigraphic assignment of seismic boundaries and sedimentological models.

The 13 wells described in Figures 1 and 2 are:

Skolp E-07
Karlsefni A-13
Snorri J-90
Hopedale E-33
Herjolf M-92
Bjarni H-81
Gudrid H-55
Cartier D-70
Indian Harbour M-52
Leif M-48 and E-38
Freydis B-87
Verrazano L-77
Roberval K-92

Technical information on these wells, including exact geographic position, water depth, height of rotary table to mean sea level, casing points, total depth reached, and release date from confidential status, can be found in Table 1.

The Labrador Shelf, between 54° and 60°N, is strongly glaciated, largely less than 200 m deep, and covers approximately 120 000 km^2 (using the 500 m isobath as the shelf break). Precambrian rocks, which outcrop onshore in Labrador, extend offshore underlying the younger shelf deposits. Pre-Mesozoic "basement" was sampled by Skolp, Karlsefni, Snorri, Gudrid, Herjolf, Hopedale and Cartier wells. The shelf is underlain by up to 5 km of Cretaceous and Cenozoic clastic wedge sediments, deposited during the rifting (Cretaceous), opening (Maastrichtian to Oligocene) and post-drift history of the Labrador Sea. Seismic stratigraphy, together with the geological well records, is the only source of information on this passive margin clastic wedge; no exposures occur onshore. Proximal parts of the clastic wedge, once covering the present day marginal channel immediately adjacent to shore, were eroded and redeposited seaward during and after the late Miocene.

Lithology

The gross lithostratigraphic sequence of the clastic wedge is as follows:

Neocomian basaltic volcano-clastics (continental) up to 300 m thick (Alexis Formation) form the basal unit on folded and faulted pre-Mesozoic rocks. Radiometric dates show a spread of between 120 and 140 Ma. This synrift formation generally yields a strong, high-amplitude seismic reflector from its upper surface. Laterally and upward it grades into mid-Cretaceous coarse sand with some shale and lignite, up to 1200 m thick (Bjarni Formation), interpreted as upper delta plain braided river and swamp sediments. Minor marine

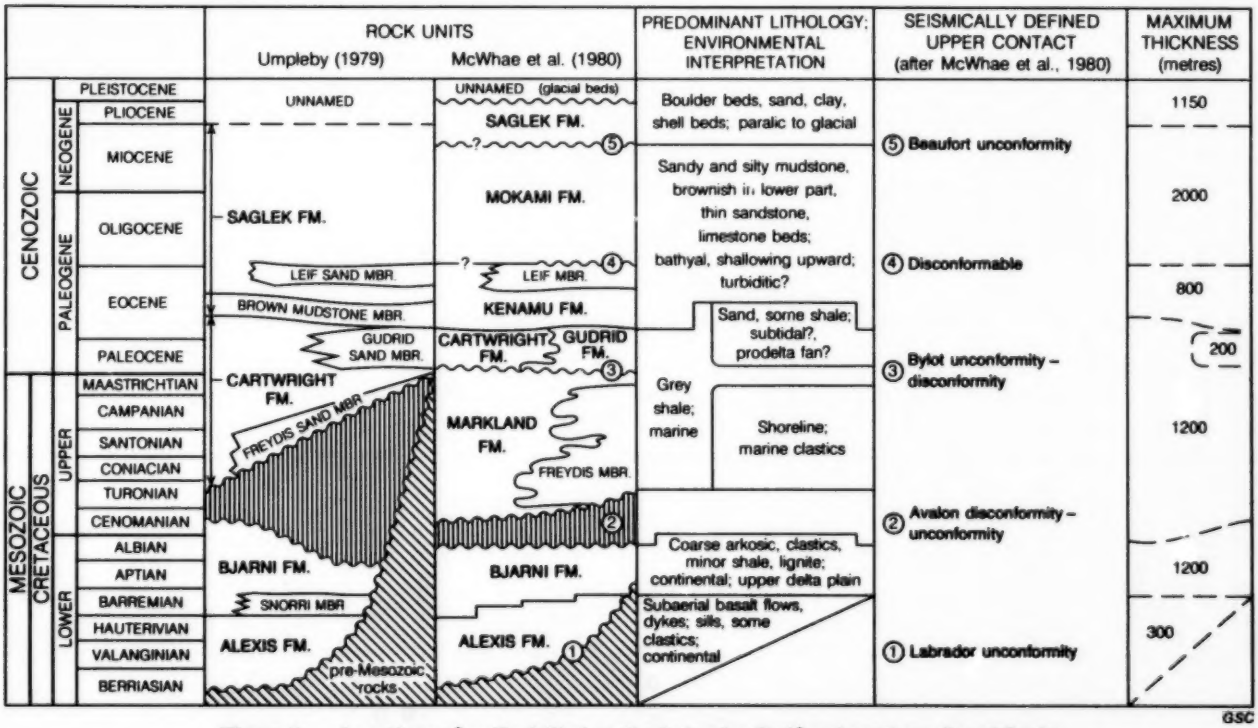


Figure 3. *Locations of wells drilled on the Labrador Shelf and northern Grand Banks.*

Table 1. Data for offshore wells

NAME	LAT.	LONG.	WATER DEPTH	ROTARY TABLE HT.	CASING POINTS	TOTAL DEPTH	RELEASE DATE	SAMPLES STUDIED	CORES
Eastcan et al. Karlsefni A-13	58°52'15.03"	61°46'42.08"	573 ft	41 ft	1650 ft. 4823 ft. 10722 ft.	13600 ft	Oct. 25/78	1760-13600 ft	Core 1 10909-10938 ft. Rec. 25.5 ft. Core 2 13602-13612 ft. Rec. 5.1 ft. SWC. 5320-10666 ft.
Total Eastcan et al. Skolp E-07	58°26'24.7"	61°46'09.5"	166.1 m	11.9 m	215.5 m 503.8 m 1339.3 m	2991.9 m	Feb. 23/81	535-2070 m	Core 2 1276.5-1250 m Rec. 2.65 m Core 3 1280-1289 m Rec. 9 m Core 4 1388-1397 m Rec. 1 m Core 5 1450-1459 m Rec. 4.35 m SWC. 1388 m-2975 m Core 6 2915.5-2921.8 m Rec. 3.3 m Core 7 2988-2992 m Rec. 3.95 m
Eastcan et al. Snorri J-90	57°19'44.52"	59°57'44.37"	462 ft.	37 ft.	579 ft. 1225 ft. 3699 ft. 8845 ft.	10531 ft.	Sept. 8/78	1260-10520 ft	Core 1 8189-8216.9 ft. Core 2 10524-10531 ft Rec. 5.2 ft. SWC. 4250-10295 ft.
Chevron et al. Hopedale E-33	55°52'24.34"	58°50'52.49"	559.9 m	11.9 m	595.5 m 857 m 1638.7 m 2057.7 m	2069.6 m	Oct. 1/80	None	Core 1 1957-1964.7 m Rec. 7.7 m SWC. 1680-2070 m
Eastcan et al Herjolf M-92	55°31'53.4"	57°44'52.9"	476 ft	88 ft.	624 ft. 1427 ft. 4546 ft. 9030 ft.	13406 ft.	Nov. 22/78	1500-13400 ft	Core 1 8636-8661 ft. Core 2 11683-11693 ft. Rec. 10.0 ft. Core 3 12434-12437 ft. Rec. 2.0 ft. Core 4 13400-13406 ft. Rec. 6.4 ft.
Eastcan et al Bjarni H-81	55°30'28.35"	57°42'05.52"	456 ft	40 ft.	577 ft. 1211 ft. 4093 ft. 7065 ft.	8251 ft	Oct. 25/76	1480-8210 ft.	
Eastcan et al. Gudrid H-55	54°54'30.02"; 54°54'29"	55°52'32.22"; 55°52'24.5"	982 ft	40 ft	1529 ft. 3465 ft. 7752 ft. 7546- 9258 ft.	9311 ft	Oct. 4/76	1660-9190 ft.	Core 1 8779.5-8792.5 ft Rec. 12.8 Core 2 9201-9211 ft. Rec. 0.5 ft.
Total Eastcan et al. Roberval K-92	54°51'35.53"	55°44'35.76"	268 m	12.5 m	318.9 m 615.7 m 1665.5 m 2770.3 m 3201 m	3874 m	July 7/84	635-3430 m	Core 1 3014-3017 m Rec. 2.8 m Core 2 3095-31125 m Rec. 6.2 m Core 3 3308-3312 m Rec. 3.3 m Core 4 3412-3423 m Rec. 11.0 m Core 5 3520-3524 m Rec. 4.0 m Core 6 3578-3582 m Rec. 4.0 m Core 7 3870-3874 m Rec. 3.5 m

Eastcan et al. Cartier D-70	54°39'02.39"	55°40'29.90"	1017 ft	41 ft	1135 ft. 1896 ft. 3807 ft.	6322 ft.	Oct. 31/77	1950-6316 ft.	Core 1 6316-6322 ft. Rec. 1.6 SWC 4100-6284 ft.
BP et al. Indian Harbour M-52	54°21'51.34"	54°23'51.81"	649 ft	42.6 ft. Re-entry 96 ft.	1000 ft. 5177 ft. 10328 ft.	7783 ft. Re-entry 12 986 ft.	Nov. 6/78	1010-7690 ft 7760-11410 ft.	Core 1 12966-12986 ft. Rec. 15.8 ft.
Eastcan et al Leif E-38	54°17'29.87"	55°05'52.17"	550 ft.	40 ft.	620 ft. 1063 ft.	3557 ft.	Aug. 1/75	1100-3560 ft.	
Eastcan et al Leif M-48	54°17'45.92"	55°07'20.17"	545 ft.	41 ft.	663 ft. 1259 ft. 3708 ft.	6165 ft.	Aug. 29/75	1300-6160 ft.	Core 1 6153-6165 ft. Rec. 12.0 ft.
Eastcan et al. Freydis B-87	53°56'13.31"	54°42'30.01"	575 ft.	40 ft.	697 ft. 1424 ft. 3665 ft.	7592 ft.	Aug. 8/77	1480-7150 ft.	Core 1 6348-6396 ft. Rec. 21 ft. Core 2 7570-7590 ft. Rec. 20 ft.
Eastcan et al Verrazano	52°26'37.67"	54°11'51.14"	182.8 m 599 ft.	12.8 m 42 ft.	680 ft. 1450 ft.	459.9 m 1509 ft.	Feb. 25/79	None	None
Mobil et al Cumberland B-55	48°24'12.57"	50°07'58.13"	639 ft.	98 ft.	904 ft. 1345 ft. 4238 ft. 10483 ft.	13571 ft.	Oct. 21/77	1410-12230 ft.	S.W.C. 1425-13078 ft.
Texaco Blue H-28	49°37'26.949"	49°18'01.942"	1486.2 m	15 m	1605 m 2055.9 m 2949 m 4420.2 m	6103 m	Aug. 26/81	2070-5190 m	
Esso Gabriel C-60	47°19'08.839"	46°53'29.598"	1113 m	24 m	1168 m 1605 m 2332 m 3639 m	5171 m	Dec. 18/81	1605-5165 m	Cores 4436.5-4445.5 m
Mobil Adolphus D-50	46°59'3.06"	48°22'28.86"	377 ft.	98 ft.	646 ft. 1011 ft. 3979 ft. 9665 ft.	12093 ft.	Jan. 5/77	1140-12072 ft.	S.W.C. 4088-12072 ft.
BP et al Hare Bay E-21	51°10'23.1"	51°04'30.2"	263 m	22 m	389 m 763 m 1571 m 3372 m	4874 m	Oct. 18/81	393-4844 m	
BP et al Bonavista C-99	49°08'05.19"	51°14'25.13"	1080 ft	41 ft.	3993 ft. 8164 ft.	12090 ft. Re-entry 12398 ft.	Aug. 12/77	1500-12060	1. 5827-4849 ft. Rec. 22 ft. 2. 8504-8533 ft. Rec. 27.1 ft. 3. 10686-10715 ft. Rec. 29 ft. 4. 12368-12398 ft. Rec. 2.3 ft.
Mobil et al Dominion O-23	47°22'49.14"	48°18'27.90"	530 ft.	100 ft.	4133 ft. 9748 ft.	13116 ft.	Oct. 21/76	1200-13116 ft.	S.W.C. 4220-9690 ft.

incursions took place during the Albian-Cenomanian eustatic sealevel highstand, prior to opening of the Labrador Sea. The Bjarni sands are hydrocarbon prospects and tested gas in the Bjarni H-81 well at 2552 m. The formation can be distinguished seismically, particularly at its upper boundary (Avalon Unconformity) and fills basement relief.

The Upper Cretaceous to Paleocene or Lower Eocene grey shale sequence, less than 1200 m thick, with minor silt and micrite intercalations, unconformably overlies older continental beds. It blankets much of the pre-unconformity relief. Its environment was shallow marine, deepening upward. The Maastrichtian to Paleocene shale is regarded as homotaxial with basal drift deposits (never drilled) in the newly formed Labrador Ocean. Several "unconformities" are useful to seismically trace the grey shale sequence, which also has distinct sonic log markers at its lower and upper boundaries (see Bjarni and Gudrid wells). Mid-Paleocene to earliest Eocene quarztose and feldspathic sands (Gudrid sands), with some shale and (detrital) coal, less than 200 m thick, have been sampled in some of the wells. It is a commercial target for hydrocarbons and tested wet gas in Snorri J-90, with similar geological and petroleum conditions to the Central and Viking Graben of the North Sea. The sands can be detected seismically, although they are geographically discontinuous, which hampers lateral extrapolation. Facies interpretations vary from delta plain (subtidal) by Umpleby (1979) to prodelta for sands and turbidites by McWhae et al. (1980). Micropaleontological information on fossil assemblages in the underlying and overlying shales suggest a neritic to bathyal paleobathymetric regime, more compatible with the latter of these two sedimentary interpretations.

An essentially Eocene sequence, over 800 m thick, consists of variably silty and sandy mudstones, predominantly grey, with brownish tinges, particularly in its lower part. This lower part contains the Brown Mudstone member with low transient time values on the sonic log. The upper part contains a laterally discontinuous sand unit (Leif sand). The shale is of bathyal depth and presumably was deposited out of suspension. Thin micritic limestone beds indicate hiatuses in clastic supply.

The upper Cenozoic sequence, a maximum 2000 m thick on seismic records, is a coarsening and paleobathymetrically shallowing-upward sequence. Several unconformities in it have been proposed, both biostratigraphically and seismically and are being equated with hiatuses in Oligocene and late Miocene time, due to local tectonic events, accentuated or overprinted by rapid eustatic changes.

The Pliocene to Quaternary section, up to 1000 m or more thick, generally was not sampled in the wells. It contains glacially derived boulder beds.

Post-Paleozoic source rocks encountered in the wells are generally immature to marginally mature. The continental Lower Cretaceous rocks are gas-prone, and the marine Upper Cretaceous-Lower Tertiary sediments more oil-prone. The "oil window" may be locally as shallow as 3-3.5 km deep. Hydrocarbons were tested in Bjarni H-81 at 2552 m, Gudrid H-55 at 2757 m, Snorri J-90 at 2497 m and Hopedale E-33 at 1957 m. For more details on the geology and petroleum exploration history the reader is referred to the list of references following.

References

Gradstein, F.M. and Williams, G.L.
1982: Stratigraphic charts of the Labrador and Newfoundland Shelves; Geological Survey of Canada, Open File 826.

Grant, A.C.
1980: Problems with plate tectonics. The Labrador Sea; Bulletin of Canadian Petroleum Geology, v. 28, no. 2, p. 252-279.

McMillan, N.J.
1980: Geology of the Labrador Sea and its petroleum potential; Proceeding Tenth World Petroleum Congress, Bucharest, 1979, v. 2, p. 165-175.

McWhae, J.R.H., Elie, R., Laughton, K.C., and Gunther, P.R.
1980: Stratigraphy and petroleum prospects of the Labrador Shelf; Bulletin of Canadian Petroleum Geology, v. 28, no. 4, p. 460-488.

Umpleby, D.C.
1979: The geology of the Labrador Shelf; Geological Survey of Canada, Paper 79-13, p. 1-34.

STRATIGRAPHY OF THE LABRADOR SHELF AND NORTHERN GRAND BANKS

F.M. Gradstein and G.L. Williams

Introduction

The exploratory wells drilled on the shelves facing the southwestern Labrador Sea have revealed the presence of up to (about) 5000 m of terrestrial to deep marine (± middle slope) sediments ranging in age from Early Cretaceous to Pleistocene.

On the Labrador Shelf these wells are:

Karlsefni A-13	Cartier D-70
Snorri J-90	Indian Harbour M-52
Herjolf M-92	Leif E-38
Bjarni H-81	Leif M-48
Gudrid H-55	Freydis B-87

and on the northern Grand Banks, they are

Hare Bay E-21	Adolphus D-50
Bonavista C-99	Blue H-28
Dominion O-23	Gabriel C-60
Cumberland B-55	

General data on each well are listed in Table 1, which includes all the micropaleontological samples studied and cores or side wall cores (SWC) collected which are curated by the Department of Energy, Mines and Resources, Dartmouth. Note that virtually all cores were in deposits not suitable for micropaleontological studies (i.e. Cretaceous terrestrial sands, Paleozoic carbonates).

Samples from these wells are predominantly cuttings (of a few tens to a few hundred grams of sediment) at 30 foot (10 m) increments. Distinct changes in microfossil preservation with depth and 13 3/8 and 8 5/8 inch casing points downhole limit the cavings problem.

Mesozoic-Cenozoic stratigraphy

The Mesozoic-Cenozoic stratigraphy using palynomorphs, shelly microfossils (mainly foraminifers), and nannofossils, is shown in Figure 4. Shelly microfossils were studied by F.M. Gradstein and F. Thomas, nannofossils by P.H. Doeven, and palynomorphs by J. Bujak and G.L. Williams. The biostratigraphic zonations have been reported previously by Barss et al. (1979), Gradstein and Srivastava (1980), Gradstein and Agterberg (1982) and Doeven (1983). The lithostratigraphic sections compiled by D. Umpleby and F. Gradstein are illustrated in Figure 2.

Interpretation of deposits and environments

The multiple chronostratigraphic interpretations for each well in Figure 4 have been combined in Figure 5 following two simple rules. Series or stage boundary discrepancies of 200 feet or less have been considered to have resulted from sampling difficulties, and the upper stratigraphic limit is based on the highest reliable microfossil evidence. The few discrepancies over 200 feet other than obvious reworkings are indicated by a hachured boundary transition zone to the right of the age column for each well.

Four basic categories of depositional environments have been classified according to both water depth and distance from shore. They are nonmarine, terrestrial; shallow neritic; deep neritic; and bathyal.

Nonmarine, terrestrial: spores and pollen, no foraminifers; Lower Cretaceous of Labrador Shelf wells.

Shallow neritic: comprises marginal marine to inner shelf sediments, laid down in water less than approximately 100 m deep. Diagnostic foraminiferal assemblages are of (very) low genus and species diversity, with rare or no planktonics; examples are the Lower Cretaceous of northern Grand Banks wells with ostracods, larger foraminifers and micro-gastropods and the Upper Cenozoic of Labrador wells. In Upper Cenozoic sections, small numbers of **Cibicidoides, Elphidium, Cassidulina, Bulimina, Melonis,** gastropods and bryozoans occur.

Deep neritic: comprises sediments laid down in water depths between 100 and 200 m. Foraminiferal genus and species diversity varies, planktonics occur locally, particularly in the southern wells. Neogene benthonic genera include **Asterigerina, Ceratobulimina, Cibicidoides, Fursenkoina, Gyroidina, Guttulina, Uvigerina, Cyclogyra, Nodosaria, Spiroplectammina, Textularia** and molluscan and bryozoan fragments. Paleogene assemblages, although much impoverished, reflect Midway type faunas. Cretaceous assemblages are of relatively high diversity, with varying numbers of ostracods, **Inoceramus** fragments and planktonics.

Bathyal (upper slope): comprises sediments laid down in water depths ranging from 200 and 1000 m. Foraminiferal genus and species diversity is high. Planktonics are abundant in the Upper Cretaceous and Upper Paleocene-Middle Eocene of the southern wells. The integration of (bio)stratigraphy, depositional history, history of Labrador Sea opening, and paleo-oceanographic/paleoclimatological events in a broad scenario for the last 65 Ma has been discussed by Gradstein and Srivastava (1980), who in turn cited many regional geological studies, particularly MacMillan (1973), McWhae and Michel (1975), Cutt and Laving (1977), Grant (1980), and Umpleby (1979).

Radiometric age determinations

Radiometric dating was undertaken on behalf of the operators of the wells drilled and reported in the Well History Reports curated by the Department of Energy, Mines and Resources, Dartmouth. Both Precambrian basement and Lower Cretaceous basalts were used. The more reliable geochronological dates (using cores, and reasonably unweathered samples) are:

Leif M-48	altered basalt below 6034 feet (1840 m)	104 ± 5 Ma 131 ± 6 Ma
Herjolf M-92	subaerially weathered basalt flow below 12 306 feet (3751 m)	122 ± 2 Ma
Bjarni H-81	whole rock, altered basalt 2510 m	139 ± 7 Ma
	whole rock basalt 2260 m	122 ± 6 Ma
Roberval K-92	whole rock: slightly porphyritic basalt Core #3: 3308-3312 m	129 ± 6 Ma
	whole rock: sheared and altered basalt Core #4: 3414.45 m	124 ± 5 Ma
	whole rock: sheared and altered basalt Core #4: 3422.9 m	122 ± 7 Ma
	whole rock: sheared and altered basalt Core #5: 3523.75 m	126 ± 5 Ma

Cartier D-70	Biotite concentrate: gneissic biotite granodiorite Core #1: 6320+ feet (basement)	1332 ± 45 Ma
Snorri J-90	Biotite concentrate: ?granodiorite; meta-igneous Core #2, 10 528 feet	1066 ± 41 Ma
Gudrid H-55	Granite 9204-9311 feet	1710 ± 57 Ma

References

Barss, M.S., Bujak, J.P., and Williams, G.L.
1979: Palynological zonation and correlation of sixty-seven wells, eastern Canada; Geological Survey of Canada, Paper 78-24, p. 1-118.

Cutt, B.F. and Laving, F.G.
1977: Tectonic elements and geologic history of the South Labrador and Newfoundland continental shelf, eastern Canada; Bulletin of Canadian Petroleum Geology, v. 25, no. 5, p. 1037-1059.

Doeven, P.H.
1983: Cretaceous nannofossil stratigraphy and paleoecology of the Canadian Atlantic margin; Geological Survey of Canada, Bulletin 356; 70 p.

Gradstein, F.M. and Agterberg, F.P.
1982: Models of Cenozoic foraminiferal stratigraphy northeastern Atlantic margin; in Quantitative Stratigraphic Correlation, ed. J.M. Cubitt and R.A. Reyment, Wiley & Sons, New York; p. 119-175.

Gradstein, F.M. and Srivastava, S.P.
1980: Aspects of Cenozoic stratigraphy and paleoceanography of the Labrador Sea and Baffin Bay; Palaeogeography, Palaeoclimatology, Palaeoecology, v. 30, p. 261-295.

Gradstein, F.M. and Williams, G.L.
1982: Stratigraphic charts of the Labrador and Newfoundland shelves; Geological Survey of Canada, Open File 826.

Grant, A.C.
1980: Problems with plate tectonics: The Labrador Sea; Bulletin of Canadian Petroleum Geology, v. 28, no. 2, p. 252-279.

McMillan, N.J.
1973: Shelves of Labrador Sea and Baffin Bay, Canada; in The Future Petroleum Provinces of Canada – their Geology and Potential, R.G. McCrossan, ed., Canadian Society of Petroleum Geologists, Memoir 1, p. 473-577.

McWhae, J.R.H. and Michel, W.F.E.
1975: Stratigraphy of Bjarni H-81 and Leif M-48, Labrador Shelf; Bulletin of Canadian Petroleum Geology, v. 23, p. 361-382.

Umpleby, D.C.
1979: The geology of the Labrador Shelf; Geological Survey of Canada, Paper 79-13, p. 1-34.

DEPTH TO BASEMENT AND SEDIMENT THICKNESS

Depth to basement

S.P. Srivastava, B. MacLean and P. Girouard

Depth to acoustic basement values were compiled from multichannel and single channel seismic reflection profile data collected along the ships tracks (Fig. 6). These include data purchased from industry on a participation basis, data collected by the Federal Institute for Geosciences and Natural Resources, Hannover, data published by other institutes, and data collected by the Bedford Institute of Oceanography on multiparameter and other cruises in this region. Figure 6 is an adaptation of those published previously by Wade et al. (1977), Srivastava (1978), and Hinz et al. (1979), incorporating additional seismic data collected during a 1979 cruise off southwest Greenland as well as depth to basement values for the southern Labrador Sea from Woods Hole Oceanographic Institution. The variations in the velocity distribution in the overlying sediments have not been taken into account in determining the depth to acoustic basement.

The quality of the data varied not only between the institutes or organizations responsible for their collection but also between regions. For example, single channel data from the Labrador shelf and slope were found to be of little use because of excessive interference from the multiple bottom reflections and lack of penetration of seismic energy through the thick sequence of sedimentary strata. Sediment thickness was also too great to be penetrated in some parts of the Labrador Basin. Basement, however, was observed on the multichannel seismic profiles in most areas.

We have considered the acoustic basement to be the pronounced reflector that constitutes the deepest continuous event recognizable on the records, even though its character changes from region to region (for details see Grant, 1975, 1980; Hinz et al., 1979).

Sediment thickness

Figure 7, Sediment thickness of the Labrador Sea, was compiled by A. Jackson, S.P. Srivastava, B. MacLean, and P. Girouard. Sediment thickness values were obtained by subtracting depth of the water from depth to basement values. Thickness values are given in seconds of two-way travel time and do not take into account any variations in the velocity of the sediments.

Acknowledgments

We wish to express our thanks to the captains and crews of the Bedford Institute of Oceanography (B10) ships and many of our colleagues from the Atlantic Geoscience Centre and the Canadian Hydrographic Service for their assistance in the collection of the data which have been incorporated in Figures 6 and 7. We would also like to thank Brian Tucholke of Woods Hole Oceanographic Institution for supplying depth to basement values for the southern Labrador Sea, based largely on the Lamont-Doherty Geological Observatory data. The assistance rendered by A.C. Grant, J.M. Woodside and D. Umpleby of the Atlantic Geoscience Centre and K. Hinz and H.-U. Schluter from the Federal Institute of Geoscience and Natural Resources, Hannover, in compiling an earlier depth to basment map which has been incorporated here, is gratefully acknowledged. We are thankful to G.L. Johnson and J. Egloff of the United States Naval Oceanographic Office for making their seismic data of the Labrador Sea available.

References

Grant, A.C.
1975: Structural modes of the western margin of the Labrador Sea; in Offshore Geology of Eastern Canada, W.J.M. van der Linden and J.A. Wade, ed.; Geological Survey of Canada, Paper 74-30, volume 2, p. 217-232.

1980: Problems with plate tectonics: the Labrador Sea; Bulletin of Canadian Petroleum Geology, v. 28, p. 252-278.

Hinz, K., Schluter, H.U., Grant, A.C., Srivastava, S.P., Umpleby, D., and Woodside, J.
1979: Geophysical transects of the Labrador Sea; Labrador to south-west Greenland; Tectonophysics, v. 59, p. 151-183.

Srivastava, S.P.
198: Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic; Geophysical Journal of the Royal Astronomical Society, v. 52, p. 313-357.

Wade, J.A., Grant, A.C., Sanford, B.V., and Barss, M.S.
1977: Basement structure, Eastern Canada and adjacent areas; Geological Survey of Canada, Map 1400A, scale 1:2 000 000.

Gravity, magnetic anomaly and bathymetry

S.P. Srivastava

Gravity (free air – Map 814 B and Bouguer – Map 814 D), magnetic anomaly (Map 814 E) and bathymetry (Map 814 A) maps included here were compiled, for the most part, from data collected jointly by Canadian Hydrographic Services and Atlantic Geoscience Centre on cruises operating from the Bedford Institute of Oceanography (BIO) in Dartmouth, Nova Scotia. Also included were the data collected on other BIO cruises throughout this region, published and unpublished data collected by Earth Physics Branch of the Department of Energy, Mines and Resources, Ottawa, and data collected from other government agencies, research institutions and exploration companies.

The gravity data on BIO cruises were collected primarily with Graf-Askania Gss-2 gravimeters mounted on Anschutz gyro stabilized platforms. In some instances, data were collected with a Graf-Askania Gss-3 gravimeter belonging to the German Hydrographic Institute, and with a LaCoste and Romberg gravimeter (S-56) belonging to the Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa. No cross-coupling corrections were applied to the data, though on some of the cruises the combined output from two Gss-2 gravimeters mounted back to back were used to obtain the gravity values which were free from cross-coupling errors. The gravity values for each cruise were adjusted for the drift of the gravimeters used. These were obtained from the calibrations of the gravimeter carried out at the beginning and end of a cruise at the nearest harbours to the survey area.

Gravity measurements from some of the BIO cruises (MN74-023, MK75-018, MK76-019, MK77-016) were adjusted by A. Folinsbee using the least squares technique of Valliant et al. (1974) to minimize the crossover errors between various tracks. For the remainder of the cruises the data were adjusted manually. Tracks that showed crossover errors of less than 10 mGal were retained and their values were adjusted manually whereas those that showed crossover errors of greater than 10 mGal were rejected. The majority of crossover errors were less than 10 mGal. The manually and computer adjusted data were then hand contoured at a scale of 1:500 000 and the contoured sheets were subsequently reduced photographically to the final scale (1:2 000 000).

The magnetic data used were collected using a marine proton precession magnetometer along ship's track shown in the map. No diurnal corrections were applied to the data but temporal variation recordings from magnetic observatories closest to the survey area were examined for periods of magnetic storms. Marine magnetic data collected during periods of magnetic storms were rejected. The anomalies were obtained by subtracting the regional field calculated according to the IGRF'65 formula (IAGA, 1969) from the observed total field at each observation point.

The magnetic data used for CHS Map 814E were collected over a 12 year period. Extremely large differences in the amplitudes of well-lineated anomalies in excess of 200 nT between cruises made the contouring difficult. These differences arose because secular variation terms used in the IGRF'65 expression do not accurately represent the secular variations for the region (Dawson and Newitt, 1978). In order to conform with the lineated pattern of the anomalies as observed from the magnetic profiles plotted along tracks, the data from various cruises were adjusted manually for minimum crossover errors. The resulting data were then hand contoured at a scale of 1:500 000 and the contoured sheets were reduced photographically to the final scale (1:2 000 000).

The primary navigation system used during the collection of most of the gravity, magnetic and bathymetry data on BIO cruises since 1972 consisted of a combination of Rho-Rho Loran-C and Satellite Navigation, giving a continuous positional accuracy of 100 m or better. Data collected prior to 1972 relied on linear interpolation between Satellite and Celestial navigation fixes. Navigation on other cruises varied and consisted of celestial navigation fixes, Loran-C and Satellite navigation. The overall navigational accuracy on these cruises varied between 2 and 3 km.

Much of the data of these maps collected on joint hydrographic and geophysical cruises have been published by the Canadian Hydrographic Office at a scale of 1:250 000 as Natural Resources Charts and also been released as Geological Survey of Canada Open Files (Macnab, 1983). They adequately portray bathymetry, Bouguer and free air gravity and magnetic anomalies for the offshore regions of the east coast of Canada. A comparison of the gravity and magnetic maps in this publication with the Natural Resource Charts for the same region will show small differences. These arise from the differences in the contouring techniques: Natural Resource Charts are produced by computer, whereas the maps in this publication were contoured by hand. For more detail, one should refer to the Natural Resource Charts where available.

Bathymetry (CHS Map 814A) was compiled by Dave Monhan of Canadian Hydrographic Services from the published Natural Resource maps and data collected on BIO and other cruises as mentioned previously.

Acknowledgments

I am most grateful to my colleagues from the Canadian Hydrographic Service and the Atlantic Geoscience Centre for their assistance in collection, reduction and compilation of the data used in these maps. The assistance rendered by A. Folinsbee for adjusting the gravity values from several cruises is gratefully acknowledged. I am also grateful to the Gravity Division, Earth Physics Branch, Ottawa, for providing published and unpublished data. I am indebted to the United States Naval Oceanographic Office and thier scientists (in particular R.H. Higgs, G.L. Johnson, P.R. Vogt and J. Egloff) for providing their magnetic data collected in the Labrador Sea over the past 10 years. I also thank Manik Talwani and Y. Kristoffersen formerly of Lamont-Doherty Geological Observatory for providing gravity and magnetic data collected in the Labrador Sea, Peter Hood and Peter McGrath of the Geological Survey of Canada for detailed unpublished contoured aeromagnetic maps over Labrador, and the Greenland Geological Survey for their aeromagnetic data from the west Greenland Shelf.

References

Andersen, O.B.
1973: Surface – ship gravity measurements in the Davis Strait, Western Greenland 1965; Geodaetisk Instituts Skrifter 3, Roekke Bind XXXIX.

Dawson, E. and Newitt, L.R.
1978: IGRF comparisons; Physics of the Earth and Planetary Interior, v. 16, P1-P6.

Grønlands Geologiske Undersøgelse
1978: Aeromagnetic reconnaissance survey offshore west Greenland for Tenneco Oil & Minerals Ltd., 1970, by Geoterrex Ltd., Geological Survey of Greenland Industry Report 78-1.

Haworth, R.T., Grant, A.C., and Folinsbee, R.A.
1976: Geology of the continental shelf off southeastern Labrador; in Report of Activities, Part C, Geological Survey of Canada, Paper 76-1C, p. 61-70.

Hood, P. and Bower, M.E.
1973: Low level aeromagnetic surveys of the continental shelves bordering Baffin Bay and the Labrador Sea; Geological Survey of Canada, Paper 71-23, p. 571-597.

IAGA Commission 2, Working Group 4
1969: International Geomagnetic Reference Field 1965; Journal of Geophysical Research, v. 74, p. 4407-4408.

Johnson, G.L., Closuit, A.W., and Pew, J.A.
1969: Geological and geophysical observations in the northern Labrador Sea; Arctic, v. 22, p. 55-68.

Johnson, G.L., Egloff, J., Campsie, J., Rasmussen, M., Dittmer, F., and Freitag, J.
1973: Sediment distribution and crustal structure of the southern Labrador Sea; Bulletin of the Geological Society of Denmark, v. 22, p. 7-24.

Kejlso, E.
1958: Gravity measurement in western Greenland, 1950-1952; Geodaetisk Instituts Skrifter 3, Roekke Bind XXVII.

Kristoffersen, Y. and Talwani, M.
1977: Extinct triple junction south of Greenland and the Tertiary motion of Greenland relative to North America; Geological Society of America Bulletin, v. 88, p. 1037-1049.

Macnab, R.F.
1983: Multiparameter mapping off the east coast of Canada; in Current Research, Part A, Geological Survey of Canada, Paper 83-1A, p. 163-171.

Srivastava, S.P.
1974: Cruise Report 74-026, C.S.S. HUDSON; Bedford Institute of Oceanography, Dartmouth, N.S.

1975: Cruise Report 75-009, Phase V, C.S.S. HUDSON; Bedford Institute of Oceanography, Dartmouth, N.S.

1978: Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic; Geophysical Journal, Royal Astronomical Society, v. 52, p. 313-357.

Svejgaard, B.J.
1959: Gravity measurements in western Greenland, 1953-1955; Geodaetisk Instituts Skrifter 3, Roekke Bind XXXII.

Valliant, H.D., Macnab, R.F., Stephens, L.E., Grant, S.T., and Cooper, R.V.
1974: Results of underwater and surface regional gravity surveys off the coast of Labrador, 1972; Department of Energy, Mines and Resources, Gravity Map Series of the Earth Physics Branch, No. 156.

van der Linden, W.J.M. and Srivastava, S.P.
1975: The crustal structure of the continental margin off central Labrador; in Offshore Geology of Eastern Canada, ed. W.J.M. van der Linden and J.A. Wade, Geological Survey of Canada, Paper 74-30, p. 233-246.

Vogt, P.R. and Avery, O.E.
1974: Detailed magnetic surveys in the northeast Atlantic and Labrador Sea; Journal of Geophysical Research, v. 79, p. 363-389.